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**A DENSITOMETRIC ANALYSIS OF IIaO FILM FLOWN ABOARD THE
SPACE SHUTTLE TRANSPORTATION SYSTEM STS #3, 7 AND 8**

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ABSTRACT

Since the United States of America is moving into an age of reusable space vehicles, both electronic and photographic materials will continue to be an integral part of the recording techniques available. Film as a scientifically viable recording technique in astronomy is well documented. There is a real need to expose various types of films to the Shuttle environment. Thus, the purpose of this study is to look at the subtle densitometric changes of canisters of IIaO film that were placed aboard the Space Shuttle #3 (STS-3).

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Introduction

Since the first major use in Skylab in 1974, scientists have used over 400 rolls of photographic film in the space environment to obtain sensitometric data. The present research team prepared 3 canisters of IIaO film along with packets of color film from the National Geographic Society, which were then placed on the Space Shuttle #3 (STS-3). The ultimate goal was to obtain reasonably accurate data concerning the background fogging effects on IIaO film as it relates to the total environmental experience. This includes: the ground based packing and loading of the film from Goddard Space Flight Center to Cape Kennedy; the effects of solar winds, humidity, and cosmic rays; the Van Allen Belt radiation exposure, various thermal effects, reentry and off-loading of the film during take-off, and 8 day, 3 hour 15 minute orbits. The development and analysis of the returned film constitute the basis of this report. The objective of this experiment was to examine the total densitometric change caused by all of the above factors.

The Laboratory for Solar Physics and Astronomy, Goddard Space Flight Center, has been using large quantities of IIaO film in its rocket and space shuttle flights. Next year, during the Ultra Violet Image Telescopic Experiment, the UIT is launching a payload which will be using 70 millimeter IIaO film. Thus, it was a requirement for the laboratory to quantitatively determine the aging effects associated with the sensitometric images on film.

IIaO film for this experiment (Figures 2 & 3) was obtained from the same roll of Kodak film Mfg. date 5-76-A5J. The film was loaded into specially prepared aluminum anodized packages that would fit aboard the Space Shuttle's Getaway Special Container. One roll of film was cut from the same stock and maintained as the control. The control film was maintained at a temperature of 22 degrees Centigrade at Goddard Space Flight Center. After the mission, the three rolls of IIaO film were shipped back to the Small Payload Section of the Laboratory for Astronomy and Solar Physics. One film and the control film were developed as Set I, while the other IIaO sample film was developed as Set II.

Using a MacBeth Densitometer, measurements were obtained from the film every 2 centimeters, developing 3 columns of data. Significant differences were found when samples were compared with the control. Sample A and Sample B had a 5.26% increase in density or fogging background, while the film developed shortly after its arrival at Goddard Space Flight Center displayed a 3.8% increase in the density or the fogging background.

An analysis of the data for each sample film aboard the Space Shuttle (Figures 5, 6, & 7) indicates variation in intensity with respect to the fogging levels as a function of position on the film. There is a tendency of more random variation toward one end of the film, but the actual orientation in the Space Shuttle is unknown. A possible theory is that the high energy cosmic rays had penetrated the aluminum film cartridges aboard the Space Shuttle causing certain secondary reactions that produce variations towards one end of the film due to the wrapping procedure used in placement of the film in the canister. Other theories suggest thermal effects cause density variations. It is known that aluminum containers tend to innately fog various UV films along with the wrapping geometry of the film within the canister.

Densitometric Response of IIaO Film Flown on STS-7

Three canisters of 35mm IIaO film were flown on STS-7 in a getaway special canister in cooperation with NASA's Plasma Physics Branch and the Naval Research's Solar Astronomy Branch. The results indicate a high degree of thermal aging during the space shuttle mission.

The future requirements for film used aboard the space lab and on the UIT (Ultra Violet Imaging Telescope) will include the following. Some ultraviolet films may have to be exposed directly to the particular vacuum of space at those altitudes, thus giving rise to concern of metallic outgassing of chemicals that may do permanent damage to the film's emulsion. The IIaO film being used on the UIT will not be exposed directly to space, but may be exposed to ionospheric fields associated with a low orbiting space shuttle. The major factor that can cause fogging is thermal exposure.

Experimental Set-Up

Using a sensitometer, a continuous roll of IIaO film was exposed for ten seconds using a General Electric Lamp 328 at 195 ma + 3 ma with a 10 - 18 hour calibration burn in time. The film was placed in three 35 mm canisters, sealed in air and attached to the getaway special canister containing other special ultraviolet films. The film was loaded in the canister approximately 22 days before the launch of the Space Shuttle Columbia.

Discussion

During the loading or pre-flight launch, post-flight analysis (Figure 8) indicates that the IIaO film had been exposed to some type of thermal aging effects. The exact nature of these effects was not apparent as we examine the temperature profiles for STS-7. But there is a concern that the rapid increase in temperature from approximately -15 °C to a temperature of +22 °C in an hour and a half after touchdown of the shuttle could explain the exaggerated thermal aging effects. There is another real concern which is associated with the fact that the shuttle landed on the West Coast, and the automatic temperature cut-off control was turned off approximately three days before the shuttle arrived at Cape Kennedy where the getaway special canister containing the film was unloaded.

Analysis of terrestrial thermal and aging effects produced similar curves as observed in this experiment, but the slopes of the individual curves tended to vary dramatically. In conclusion, there were observed densitometric changes in comparing the control films and the flight film, though both had been developed at the same time as the flight film received from STS-7.

Experimental Set Up for STS-8

This research team was able to use one of the canisters to place four rolls of IIaO film of STS-8, one roll of Ilford G5 nuclear emulsion, and one roll of a new batch of IIaO. The Naval Research Laboratory setup was using a very sensitive ultraviolet film to study the effects of space on the ultraviolet emulsions. The shuttle orbit was low enough to expect some minimum cosmic ray damage to the film as well as tracks on the nuclear emulsion film. The Getaway Special was aligned in the bay of the shuttle with bay portals pointed to the earth for cooling purposes as shown in figure 9.

The temperature profiles for STS-7 and STS-8 were very similar, going from a temperature of approximately 23 degrees centigrade before launch to a temperature of -22 degrees centigrade during the flight. This increased the density of the wedges. The major differences between STS-7 and STS-8

occurred because STS-7 had to land in California where the automatic temperature control devices and appropriate air conditioning units for the shuttle cargo were not present. Once the shuttle had landed, one can measure the diurnal temperature variations (Figure 8). Terrestrial experiments have shown that less dense wedges produce densitometric increases as the temperature increases (Figure 12) over a number of days. The diagram shows the effects of the first 3 step wedges including the aging effect of the background at 32 degrees. The lowering of the temperature decreases the slope of the family curves for each of the darker step wedges. Figures 11 & 14 (aging effects) show the slope variation at 21 degrees and at 32 degrees over a 90-day period.

A most interesting effect occurs at the darker patterns. They tend to drop in density, while the lighter patterns tend to increase in density. Furthermore, the IIaO film seems to perform nonlinearly for temperature values above 67 or 68 degrees (Figure 13). The least dense step wedges tend to show dramatic increases in density above 68 degrees Centigrade while the darker wedges show a reduction of temperature above 70 degrees. The slopes of these films are increased further when the ambient temperatures seem to increase.

A brief examination of the aging effects will assist us in understanding the observed effects on the film caused by exposure to the space environment of the shuttle (Figure 14). We used a microdensitometer to contrast and compare the terrestrial film as well as the shuttle flight film (Figure 15). Using this technique we were able to calculate the signal to noise ratio for flight as well as for control film. On board STS-8 the signal to noise ratio increased while the control film decreased. The signal to noise ratio computed for STS-7 shows that at higher exposure the signal to noise ratio is less than for the flight films (Figure 16). But at lower exposures the control and flight film seem to have larger signal to noise ratios (Figure 17). This difference may be caused by additional thermal activity within the canister as shown in Figure 17 and the lack of appropriate air conditioning equipment at the California landing site.

Signals to Noise Ratio of Aging Film

Analysis of the signals to noise ratio for IIaO film aged 8, 9, 21, 17, and 71 days indicates that a certain amount of aging reduces the signal to noise ratio over the short term, but will increase the signal to noise ratio over long periods of time (Figure 18).

An examination of the interaction of protons of varying dosages and energies indicates that the very light wedges are very sensitive to proton interaction with the emulsion while the very dark patterns tend to be less sensitive to very high MEV protons (Figure 19). MEV vs. dosage figures were obtained by using the Harvard University Cyclotron.

Using the Harvard University Cyclotron, we bombarded the IIaO film with alpha particles, (Figure 18) searching for parallel interactions in the space shuttle due to cosmic rays as from the cyclotron. We bombarded the IIaO film using the alpha particles at 47 MEV, 79 MEV and 153 MEV for the 6.8 rad dosage. We expected to see similar results when we examined the films from the shuttle. But we did not see such effect (Figure 19). There is a difference in the front part of the curve, but the toe and the shoulders did not seem to respond; as a result we do not think that there was any dramatic cosmic ray activity (Figure 20A).

Microdensitometric Analysis

When comparing similar step wedges that have been aged from 3 to 71 days, one can immediately see an increase in granularity. However, this is not consistent for all step wedges as it is for the middle wedges. The denser the wedges, the more one observes the converse of less granularity. Furthermore, as aging occurs, granular definition between step wedges seems to decrease, while other step wedges under densitometric aging will produce a heavier granularity indicative of increased grain structure.

Microdensitometric Comparison of Control Vs. Flight Film

The control film of STS-8 for step wedges 3 has larger grain structure than the flight film. Similarly on STS-8 strip 4, a new batch of IIaO film indicates a slight increase of granularity toward the darker wedges (Figure 24). Conversely, the least dense step wedge controls are heavier than the traces for the flight film (Figure 25). Microdensitometric traces of step 4 and strip 4 tend to illustrate very small changes. Finally, traces from STS-8 again show greater granularity for the flight film than for terrestrial controls (Figure 27).

A new approach to the examination of the IIaO film emulsion is the use of the scanning electron microscope to investigate surface grains and their structure. Varying the voltage of the probe electrons, we are able to examine grain structure under the surface of the emulsion at the proper accelerating voltage of the electrons. All the IIaO films were coated with gold palladium using standard sputtering techniques.

Using about 1,000X Magnification (Figure 27), it became very evident that the energy of the electrons within the scanning electron microscope striking the emulsion is very crucial in terms of the viewing of the grain structure. What we want to do in the future is to look at the aged film and see exactly how these grains change (Figure 28).

We found that a working voltage for SEM ISI SS 40 somewhere between 2 kilovolts and 10 kilovolts is sufficient to produce clear images without flaring. The flaring of the image from the SEM produces a 4-8% increase in the total area of the grain under investigation from direct measurements of the micrograph.

But as the energy of the electrons increases, one notices that there is a flare effect, each grain spreading out brightly (Figure 29). Then one begins to see some of the grains beneath the surface of the emulsion. So using this scanning electron technique, we can examine some of the grains just below the surface if the charging voltage is appropriate.

We also attempted to look at the wedges under the electron microscope. The extreme left represents the least dense, and the extreme right represents the most dense. (Figures 33, 34, 35 & 36 A&B). Of course, as the density increases, the size of these grains seems to decrease. Using this technique, one can measure with ease and acquire some statistical understanding (Figure 38).

Qualitative analysis techniques of energy dispersion reveal a very large silver peak along with traces of copper sodium and sulfur and argon peaks as shown in Figure 38. These trace element peaks are associated with the elements used in the development process and other materials in the emulsion.

Reciprocity Failure of IIaO Film

Reciprocity failure was examined for IIaO spectroscopic film. The failure was examined over two ranges of time from one second to thirty-one seconds and one minute to 180 minutes. The variation of illuminance was obtained by using thirty neutral density filters. A standard sensitometric device imprinted the wedge pattern on the film as exposure time was changed. Our results indicate reciprocity failure occurring for higher density patterns within the first minute. Multiple failure occurs at 13, 30, 80, and 180 minutes.

Materials and Methods

Twenty-seven wedge patterns were placed on IIaO spectroscopic film in total darkness using a light sensitometer with a 24 hour burn in time for the bulb. Each film section was exposed to the light sources for a specific period of time. Time intervals were the following: 1-30 seconds and 1-11, 15, 19, 22.5, 25, 27, 30, 35, 40, 45, 58, 90, 125, and 180 minutes respectively.

The film was then developed using Kodak D-19 developer, rapid fixer, hypo-clearing agent and photo-flo solutions. The following development procedure was used for each film section: In absolute darkness, and a water bath at a temperature of 20c + 1.5c, one section of film was placed in Kodak D-19 developer and gently agitated for four minutes using a specific soak and agitating pattern. It was washed in water for 30 seconds, shaken, then placed in Kodak rapid fixer solution, using the exact same pattern of agitation and soaking, and gently agitated for four minutes. It was then removed, rinsed in water for 30 seconds, washed in water for one minute, then hung to dry. After developing, the optical densities of the wedge patterns were read using a MacBeth Densitometer.

Results

An examination of the reciprocity failure for the 1 to 30 second exposure periods (i.e., a separate wedge pattern that was exposed to an amount of light from 1 to 30 seconds sequentially) reveals that for two separate batches of film whose histories of use were different, there is some reciprocity failure occurring at the darker wedge patterns. While an examination of the very light patterns further shows the trend of reciprocity failure at the 30th and 31st seconds, it should be noted that the very darkest patterns have a marked decrease in reciprocity failure around the 30 second interval, with other variations occurring at 10, 15 and 19 seconds consistently with each variation of the pattern.

An examination shows that reciprocity failure minimum points occur at 13 minutes, 20 minutes, 30 minutes, and 90 minutes, with a less defined failure at +80 minutes. The middle density wedges indicate the same reciprocity failure points occurring at the same time. The darkest wedges show remarkable stability for the first 10 minutes exposure, but dramatic failures occur at 11 and 20 minutes. Very dramatic reductions occur at 30 minutes.

Conclusion

For exposure times of 30 to 31 seconds, darker wedges experience failure more than light wedge patterns. This indicates that the lighter wedges are less sensitive to Reciprocity Failure at short exposure times. As the exposure time increases, there appear to be some migration of grains in the darker wedges; especially the last three columns which gave an appearance that a double exposure had occurred. There is also an increased darkening of the film with increased exposure times. Fogging of the film is prevalent at 30, 45, 58, 90, and 180 minutes, again with increased exposure times. An examination of the reciprocity

failure from 1 to 180 minutes completely demonstrates the following: (a) The reciprocity failure minimum points are at 13 minutes, 20 minutes, 30 minutes, and 90 minutes, whereas, less defined failure occurs at 11 minutes. The light and middle density wedges showed this result. Darker wedges (b) show remarkable stability for the first 10 minutes of exposure, but reductions occurred at 11 minutes, 20 minutes, and dramatic reductions at 30 minutes.

Summary

The results of these studies have implications for the utilization of the IIaO spectroscopic film on future shuttle and space lab missions. These responses to standard photonic energy sources will have immediate applications in a terrestrial or extraterrestrial environment with associated digital imaging equipment.

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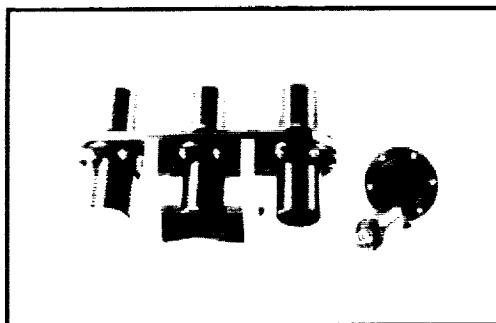


Figure 2



Figure 3

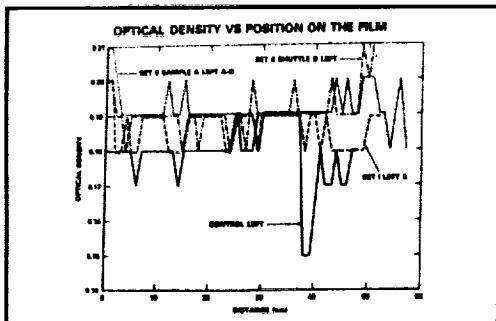


Figure 5

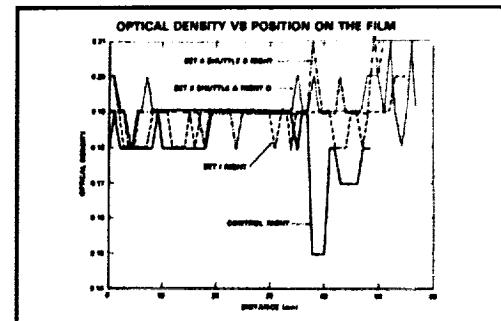


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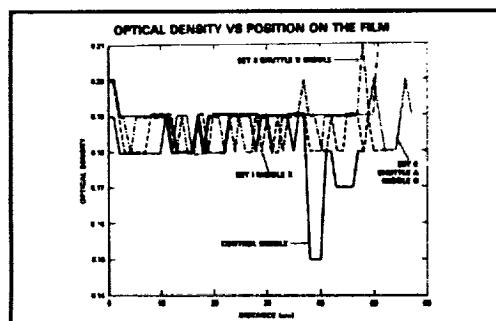


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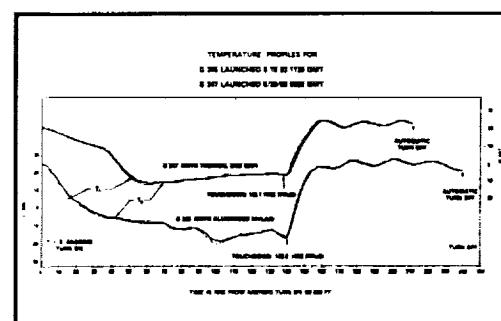


Figure 8

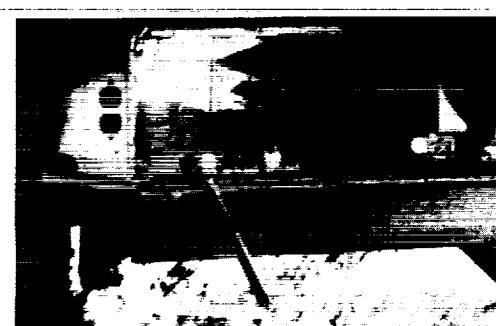


Figure 9

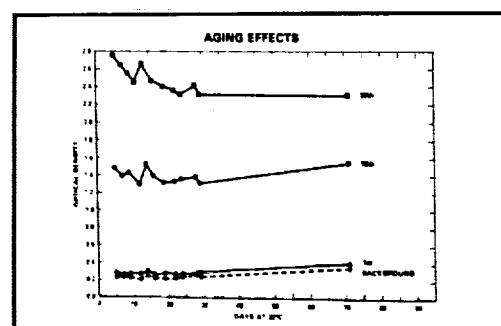


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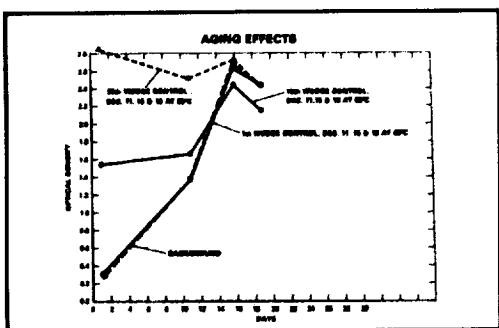


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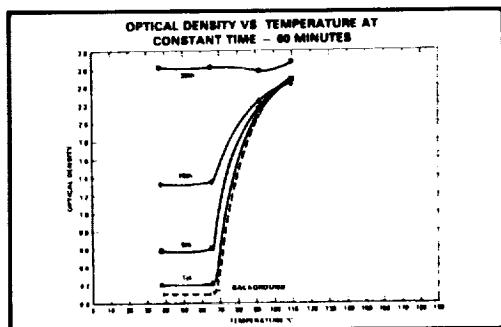


Figure 13

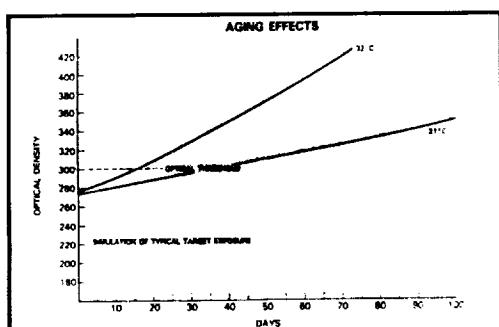


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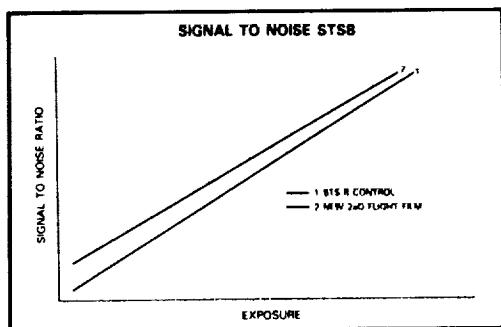


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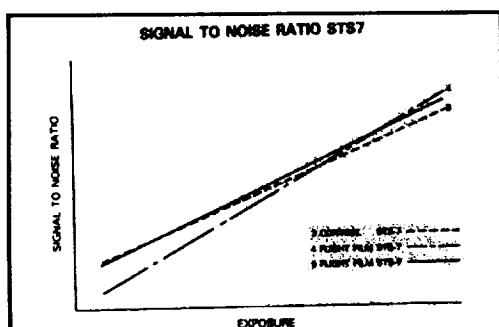


Figure 16



Figure 17

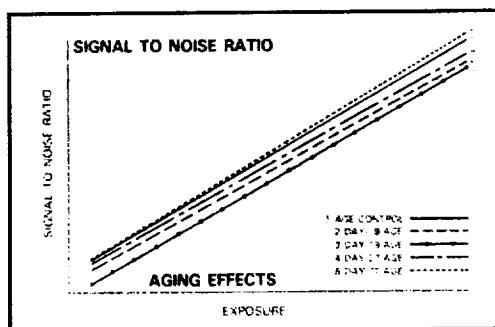


Figure 18

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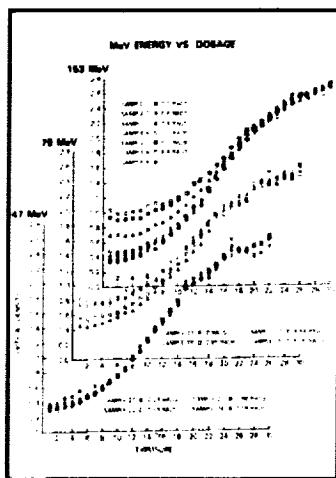


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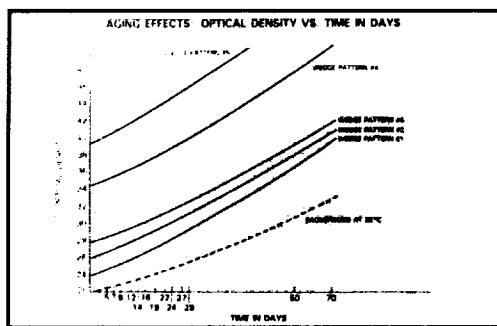


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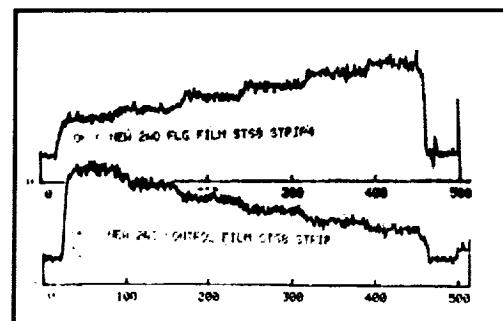


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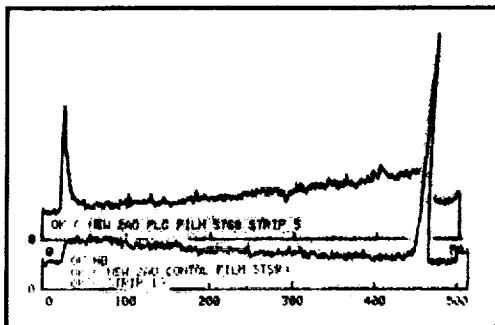


Figure 25



Figure 27

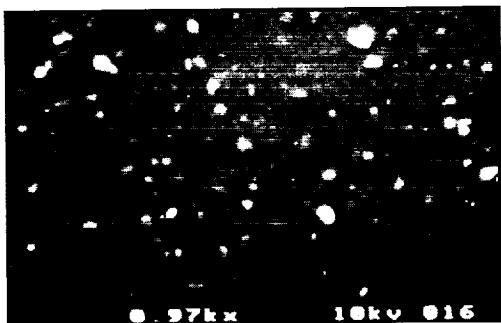


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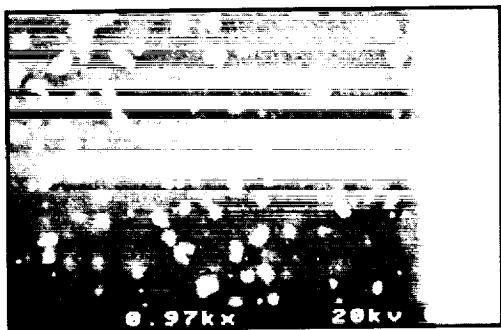


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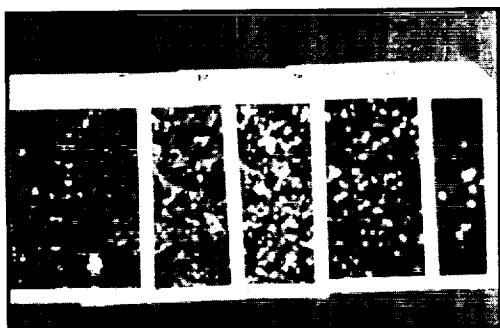


Figure 33



Figure 34



Figure 35

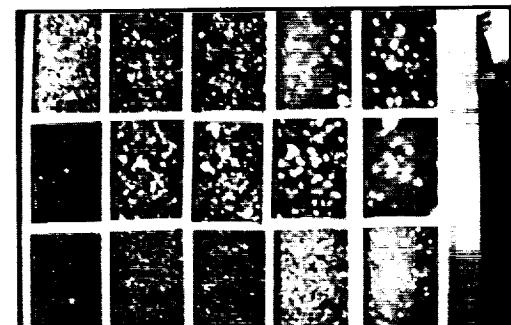


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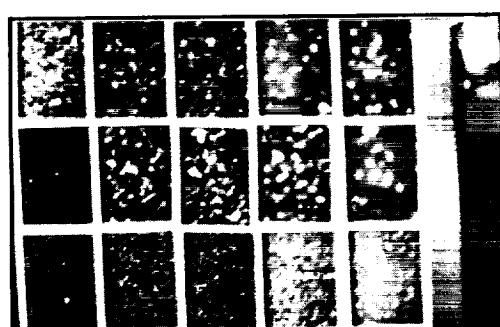


Figure 36 B

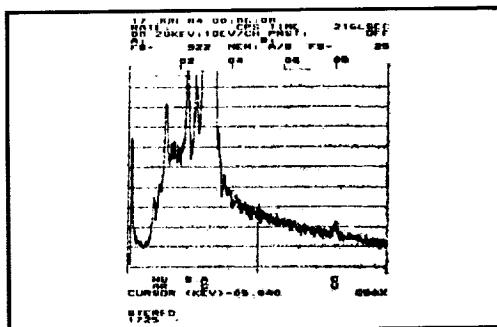


Figure 38